
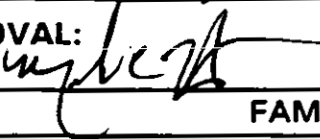
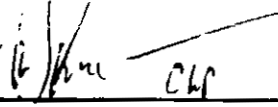


**ATTACHMENT J.4.97**  
**OPTIMIZATION OF RADIATION PROTECTION**  
**SD-1023**

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**Description:** Provide the basis for utilizing cost-benefit analysis/optimization techniques when estimating the performance of alternative radiation protection practices.

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## 1.0 PURPOSE

The purpose of this technical basis is to identify the methodology used to perform cost-benefit analysis/optimization techniques.

## 2.0 SCOPE

The information presented in this technical basis applies to the utilization of cost-benefit analysis during the selection of the optimum radiation protection practices by FERMCO.

## 3.0 DEFINITIONS

- 3.1 **Absorbed dose (D)** - Energy absorbed by matter from ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad.
- 3.2 **Committed dose equivalent ( $H_{T,50}$ )** - the dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed dose equivalent is expressed in units of rem.
- 3.3 **Committed effective dose equivalent ( $H_{E,50}$ )** - the sum of the committed dose equivalents to various tissues in the body ( $H_{T,50}$ ), each multiplied by the appropriate weighting factor ( $w_T$ )--that is,  $H_{E,50} = \sum w_T H_{T,50}$ . Committed effective dose equivalent is expressed in units of rem.
- 3.4 **Collective dose** - The sum of the Total Effective Dose Equivalent (TEDE) values for all individuals in a specified population. Collective dose is expressed in units of person-rem.
- 3.5 **Cumulative total effective dose equivalent** - the sum of the total effective dose equivalents recorded for an individual for each year of employment at a DOE or DOE contractor site or facility, effective January 1, 1989.
- 3.6 **Deep dose equivalent** - the dose equivalent derived from external radiation at a depth of 1 cm in tissue.
- 3.7 **Dose equivalent (H)** - The product of the absorbed dose (D) (in rad or gray) in tissue, a quality factor (Q), and all other modifying factors (N). Dose equivalent is expressed in units of rem.
- 3.8 **Effective dose equivalent ( $H_E$ )** - the summation of the products of the dose equivalent received by specified tissues of the body ( $H_T$ ) and the appropriate weighting factor ( $w_T$ )--

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that is,  $H_E = \sum w_T H_T$ . It includes the dose from radiation sources internal and/or external to the body. The effective dose equivalent is expressed in units of rem.

- 3.9 **Quality factor** - the principal modifying factor used to calculate the dose equivalent from the absorbed dose; the absorbed dose (expressed in rad) is multiplied by the appropriate quality factor (Q).
- 3.10 **Total effective dose equivalent (TEDE)** - the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures). For purposes of compliance, deep dose equivalent to the whole body may be used as effective dose equivalent for external exposures.
- 3.11 **Weighting factor ( $w_T$ )** - the fraction of the overall health risk, resulting from uniform, whole body irradiation, attributable to specific tissue (T). The dose equivalent to tissue, T, is multiplied by the appropriate weighting factor to obtain the effective dose equivalent to that tissue.

#### 4.0 OPTIMIZATION OF RADIATION PROTECTION

One of the components of the system of dose limitation recommended by the International Commission on Radiation Protection (ICRP) Publication 26 is that *"all exposures shall be kept as low as reasonably achievable, economic and social factors taken into account"*. In ICRP Publication 37, this component was referred to as *"the optimization of radiation protection."*

Optimization of radiation protection is a process by which the optimal level of radiation protection is identified and achieved. The optimal level of radiation protection for a particular radiation protection practice depends on many factors, including the cost of the practice, the reduction in risk (dose) from the practice, and the detriment associated with dose. Radiation doses are ALARA only when these factors are properly balanced. If an imbalance exists, either too many resources or too few resources are spent to reduce occupational radiation doses. Cost-benefit analysis techniques can be used to ensure that proper considerations are given to both the costs of a radiation protection practice and the benefits derived from that practice.

##### 4.1 Application of Optimization

The process of optimization requires that all viable options be expressed in like terms in order to make a comparison. Cost-benefit analysis methodology expresses the radiation protection practice and the detriment associated with the potential exposure in monetary units.

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NOTE: This convention is not to be misconstrued as equating exposure to dollars, but as a tool that will aid in the decision making process combined with full consideration of social, economical, technical, and public concerns when optimizing radiation protection.

#### 4.2 Cost-Benefit Analysis Technique

The commission of ICRP Publication 26 recommends using the following equality when performing cost-benefit analysis.

$$B = V - (P + X + Y)$$

Where:

- $B$  = Net benefit of the introduction of a practice taking into account social, technical, economic, practical, and public policy considerations.
- $V$  = Gross benefit of the introduction of such practice.
- $P$  = Basic production cost of the practice, excluding the cost of radiation protection.
- $X$  = Cost of achieving a selected level of radiation protection.
- $Y$  = Cost of the detriment resulting from the practice at the selected level of radiation protection.

The commission of ICRP Publication 37 identifies the following with respect to the above equation.

*"Optimization of radiation protection can be generally limited to the selection of the best available combination of cost of radiation protection,  $X$ , and cost of detriment,  $Y$ , by minimizing the sum  $(X + Y)$ ... - assuming  $V$  and  $P$  are independent of the protection parameters."*

This simplified expression is identified as the optimization function ( $U$ ).

$$U = X + Y = \text{minimum}$$

Where:

- $Y$  =  $Y(\omega)$
- $X$  =  $X(\omega)$
- or,  $\psi[X(\omega), Y(\omega)] = 0$

Note: The pair of equations  $X(\omega)$  and  $Y(\omega)$  represent the parametric form of the general function  $\psi$  and are defined functions of the radiation protection parameter,  $\omega$ .

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The cost of achieving a selected level of radiation protection (X) is determined using standard costing techniques, whereas the cost of the detriment resulting from the practice at the selected level of radiation protection (Y) is related to the cost assigned per unit of exposure.

#### 4.3 Detriment (Y)

ICRP Publication 37 defines the detriment (Y) as the mathematical expectation of the amount of harm in the exposed group of people, taking into account both the probability and the severity of the different possible harmful effects. Harmful effects include the stochastic and non-stochastic effects, (adding up to what is sometimes called the objective health detriment), as well as the concern and anxiety of the individuals at risk and any adverse consequence for the comfort of these individuals due to restrictions imposed because of the occurrence of radiation exposure.

The detriment (Y) consists of the objective health detriment and other components of the detriment. The optimization of radiation protection expresses the cost of the detriment as;

$$Y = \alpha S + \beta \sum_j N_j f_j(H_j)$$

or

$$Y = \alpha S + \sum_j \beta_j N_j H_j$$

Where:	$S$	= Collective dose due to the installation, source or practice under consideration.
	$\alpha$	= Monetary cost assigned by the decision maker to the unit of the collective dose quantity, for example the cost assigned to a person-rem.
	$H_j$	= Dose equivalent in the individuals of group $j$ .
	$N_j$	= Number of these individuals.
	$f_j(H_j)$	= One individual of an exposed group expressed as a function of the individual dose.
	$\beta$	= Monetary cost assigned by the decision maker to a unit of these components of detriment.
	$\beta_j$	= Monetary cost assigned by the decision-maker to the unit of dose equivalent delivered to the $j$ th group.

In actual application of the cost-benefit methodology, the values assigned to  $\alpha$  and  $\beta$  by the decision maker will depend on a value judgement of the relative weight of the different components of the detriment. It should be pointed out that in many situations

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the following expression would be a good approximation to the cost of detriment, even if  $\beta$  is not taken to negligible.

$$Y = \alpha S$$

This would be the case if ~~all~~ individual doses are small and if the  $f_i(H)$  functions decrease steeply with decreasing doses.

#### 4.4 Value of $\alpha$

ICRP Publication 37 states the following with respect to the objective health detriment:

*"Optimization of radiation protection takes place in a region where, with few exceptions, individual doses are always below the dose limits. Therefore, only the induction of somatic and hereditary stochastic effects of radiation would contribute to the deleterious health consequences, since non-stochastic effects should be prevented."*

ICRP Publication 37 states the following with respect to the value of  $\alpha$ :

*"Over the years there have been a number of attempts to define a value of the unit collective dose so that estimates of collective dose could be conveniently converted into monetary units. Without correcting prices to any particular year the values have ranged from approximately US \$1 000 per man sievert to approximately US \$100 000 per man sievert."*

Additionally, 10 CFR 50, Appendix I, states the following:

*"The value \$1000 per total body man-rem and \$1000 per man-thyroid-rem (or such lesser values as may be demonstrated to be suitable in a particular case) shall be used in this cost benefit analysis."*

NOTE: Although 10 CFR 50 is not a governing document at the FEMP, it is identified to demonstrate that the value of \$1000 per person-rem is an accepted value by other agencies.

Since this information is derived from documents published in 1983, to add an additional degree of conservatism, the value of \$1000 is compounded at an annual rate of 7 percent and expressed in 1995 dollars. The 1995 value of the objective health detriment would approximately be \$2250 per person-rem.

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#### 4.5 Additional Components of the Detriment

ICRP Publication 37 identifies the other component of the detriment that reflects the non-health related aspects. These components relate the perceived aversion to the risk of radiation exposure and are expressed as follows:

$$\beta \sum_j N_j f_j(H_j)$$

ICRP Publication 42 identifies that if the additional components of the detriment are proportional to components of the collective dose the term could be reduced to the following:

$$\sum_j \beta_j N_j H_j$$

The value of  $\beta$  should reflect the importance of personnel and public relations aspects of minimizing radiation exposure. Depending on the facility, the value of  $\beta$  based only on these considerations could exceed the value of  $\alpha$  by up to an order of magnitude. For applications where other costs are involved in the exposure of persons to radiation (such as the costs that are incurred when worker doses approach administrative or regulatory limits) the value of  $\beta$  used for optimization analyses should be set correspondingly higher.

#### 4.6 Discussion of When the $\beta$ Term is Applicable

In order to determine when the  $\beta$  term (i.e., other components of the detriment) is applicable an evaluation of the occupational dose limit is needed. This evaluation will identify the level of exposure where the  $\beta$  term is ~~required to be used to evaluate the detriment (Y).~~ *noting contribute to*

- A. The basis for the occupational dose limit, presented in National Council on Radiation Protection and Measurements (NCRP) Report number 116, is as follows.

*"The philosophy of NCRP, as established in this report [NCRP report no. 116], is that for occupational exposure, the level of protection provided should ensure that potential stochastic effects are maintained ALARA, commensurate with social and economic factors but, in any case, the risk to an individual of a fatal cancer from exposure to radiation should be no greater than that of fatal accidents in safe industries."*



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and;

*"the radiation-protection system should result in a average annual risk of fatal cancers of the order of  $10^{-4}$  or less."*

- B. The detriment associated with a rem is included in ICRP Publication 26, 37, and 42, and is as follows;

*"The value of  $R$  [total risk for whole body irradiation] is taken to be  $1.65 \times 10^{-2}$  per sievert [ $1.65 \times 10^{-4}$  per rem]."*

- C. The exposure level where  $\beta$  is applicable can be determined using the relationship identified in ICRP Publication 37 the equates the objective health detriment to one person for a given value of  $R$ .

$$G_{H,1} = RH_E$$

Where:  $G_{H,1}$  = Objective health detriment to one person  
 $R$  = Total risk for whole body irradiation per rem  
 $H_E$  = Effective Dose Equivalent (EDE), rem

Using this relationship the value for  $H_E$  can be determined that could result in a total detriment of  $10^{-4}$  or greater to an individual.

$$H_E = \frac{G_{H,1}}{R} = \frac{1 \times 10^{-4}}{1.65 \times 10^{-4}} = 0.606 \text{ rem}$$

- D. The value of  $R$  has been revised in ICRP Publication 60 for the total risk of whole body irradiation ( $R$ ) to  $4 \times 10^{-4}$  per rem for fatal cancers and  $0.8 \times 10^{-4}$  per rem for severe hereditary effects for a total detriment of  $4.8 \times 10^{-4}$  per rem. Although the recommendations of ICRP Publication 60 are still under consideration by the Department of Energy and the basis for the 10 CFR 835 exposure limits are based on ICRP Publication 26 (i.e, a total detriment of  $1.65 \times 10^{-4}$  per rem) it is considered here for conservatism. The value of  $H_E$  for the revised value of  $R$  and the subsequent total detriment to one person, such that  $G_{H,1}$  is  $10^{-4}$  or greater is evaluated below.

$$H_E = \frac{1 \times 10^{-4}}{4.8 \times 10^{-4}} = 0.208 \text{ rem}$$

Therefore, the  $\beta$  term becomes a necessity when an individual, on average, has an EDE greater than 0.2 to 0.6 rem per year on a routine basis, depending on the

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value used for the total risk for whole body irradiation (R). Taking an average of these values results in an exposure of 0.4 rem per year.

- E. The value of the  $\beta$  term, when applicable, should be based on the following equation, assuming the additional components of the detriment are proportional to components of the collective dose.

$$\beta_j = \left( \frac{H_j}{5 \text{ rem}} \right) \times \beta_{\max}$$

Where:  $\beta_{\max}$  = Maximum monetary cost assigned by the decision-maker to the unit of dose equivalent.

The value of  $\beta_{\max}$  is a specific value based on the level of expertise required by the workforce for an activity. The factors needed to evaluate the value of  $\beta_{\max}$  will usually depend on the following criteria. These criteria are not all inclusive and are provided to illustrate the potential areas that may need to be considered.

1. Cost of hiring additional workers.
2. Cost to train additional workers.
3. Other costs that will impact the schedule for the activity.

#### 4.7 Exposure Level Requiring Cost-Benefit Analysis

The level of exposure that requires applying cost-benefit techniques to determine the optimum radiation protection practice is based on the public dose limit. The passage that follows identifies the basis for the public dose limit.

NCRP Report number 116 relates that the basis for the public dose limit (i.e., 0.1 rem per year) is *"designed to limit the exposure of members of the public to reasonable levels of risk comparable with risks from other common sources i.e.,  $10^{-4}$  to  $10^{-6}$  annually."*

Additionally, the report discussed that an annual effective dose equivalent (EDE) in excess of 0.1 rem up to 0.5 rem per year, usually to a small group of people, need not be regarded as especially hazardous, provided it does not occur often to the same groups and that the average exposure to individuals in these groups does not exceed an average cumulative EDE of about 0.1 rem.

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#### 4.8 Summary

The equality that defines the detriment is as follows:

$$Y = \alpha S + \sum_j \beta_j N_j H_j$$

Where:

- Y = Cost of the Detriment (\$)
- $\alpha$  = Cost per unit collective dose, health related (\$/person-rem)
- S = Collective dose (person-rem)
- $\beta$  = Cost per unit collective dose, health and non-health related, (\$/person-rem)
- N = Number of individuals (persons)
- H = Average dose equivalent to an individual in jth group (rem)
- j = Group of individuals being assessed

From the equality it can be discerned that  $S = \sum_j N_j H_j$ . The above equality can be re-written as follows:

$$Y = \alpha \sum_j N_j H_j + \sum_j \beta_j N_j H_j$$

The term  $\beta_j$  is expressed as the following equality:

$$\beta_j = \frac{H_j \beta_{\max}}{5 \text{ rem}}$$

Where:

$\beta_{\max}$  = Maximum cost per unit collective dose for one individual (\$/person-rem)

Substitution yields the following:

$$Y = \alpha \sum_j N_j H_j + \frac{\beta_{\max}}{5 \text{ rem}} \sum_j N_j H_j^2$$

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When performing a cost benefit-analysis, of viable radiological control measure, this equality is used in the following manner.

$$H_j < 0.1 \text{ rem} \rightarrow Y = 0$$

$$0.1 \text{ rem} < H_j < 0.4 \text{ rem} \rightarrow Y = \alpha \sum_j N_j H_j$$

$$H_j > 0.4 \text{ rem} \rightarrow Y = \alpha \sum_j N_j H_j + \frac{\beta_{\max}}{5 \text{ rem}} \sum_j N_j H_j^2$$

The numerical values for  $\alpha$  and  $\beta_{\max}$  must be known to evaluate Y (i.e., Detriment, health and non-health related). The value of  $\alpha$  is \$2250/person-rem. The value of  $\beta_{\max}$  is a variable based on the cost assigned by the decision maker. The conservative approach for the value of  $\beta_{\max}$  would involve replacing a member of the work force, due to approaching either an administrative control level or regulatory dose limit. The costs related to this are as follows.

Hiring process	\$1,000
Training (Radiological Worker II training)	\$1,200
Basic salary (Cost to FERMCO)	\$50,000
TOTAL (value of $\beta_{\max}$ )	\$52,200

To provide a deeper insight into the application of cost-benefit analysis, the following example is presented.

Four viable Radiation Protection Measures (RPMs) have been identified. The First option involves no RPM (i.e., the do nothing option). The next three options involve various RPMs that will reduce the average dose (H).

Viable Options	Average dose (H) rem	RPM Cost (X) \$	Number of workers	Total Detriment (Y) \$	Optimization Function (U) \$
1	1.2	0	4	70934	70934
2	1.0	10000	4	50760	60760
3	1.0	15000	4	50760	65760
4	0.8	30000	6	50890	80890

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A review of the above table reveals, for this cost-benefit analysis, that option 2 would be the best choice. Although the average dose for option 4 is the least, the other factors make it less than the optimum choice due to the cost of the RPM and the number of workers.

## 5.0 REFERENCES

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